**AMERICAN SOCIETY OF HEATING, REFRIGERATING**

**AND AIR-CONDITIONING ENGINEERS, INC.**

**1791 Tullie Circle, NE Atlanta, GA 30329 404-636-8400**

**TC/TG/TRG MINUTES COVER SHEET**

**(Minutes of all meetings are to be distributed to all persons listed below**

**within 60 days following the meeting.)**

**TC/TG/TRG NO. TC4.11 DATE: 2 March 1999**

**TC/TG/TRG TITLE: Smart Building Systems**

**DATE OF MEETING: 26 January 99 LOCATION: Chicago**

| Members Present | Appt | Members Absent | Appt | Ex-Officio Members and Additional Attendance |
|---|---|---|---|---|
| Jim Braun | 99-01 | Jeff Haberl | 98-02 | Peter Armstrong |
| Todd Rossi | 99-03 | Ron Kammerud | 96-99 | Dan Beebe |
| John Mitchell | 96-00 | Doug Nordham | 96-00 | Bob Benzuly |
| Michael Kintner-Meyer | 99-03 | Patrick O'Neill | 96-99 | David Bornside |
| Carol Lomonaco | 96-99 | Mark Bailey (CM) | 98- | Michael Brambley |

| | | | | |
|---|---|---|---|---|
| Arthur Dexter<br>(int'l member) | 96-00 | Dale Hitchings | | Dave Branson |
| Philip Haves<br>(int'l member) | 96-00 | Kirk Drees (CM) | 96- | Marty Burns |
| Rich Hackner | 98-02 | Tom Engbring (CM) | 99- | William Carroll |
| John House | 99-03 | Ira Goldschmidt (CM) | 98- | Daniel Choiniere |
| Steve Blanc | 99-03 | Brian Kammers (CM) | 96- | Pamela Darrah |
| Mark Breuker | 99-03 | Barry Reardon (CM) | 99- | Wayne Dunn |
| Barry Bridges | 98-02 | Tim Ruchti (CM) | 96- | Barrett Flake |
| James Gartner | 98-02 | Greg Schoenau (CM) | 96- | Ken Gillespie |
| Les Norford (CM) | 99- | Peter Simmonds (CM) | 98- | Young Duk Ju |
| George Kelly (CM) | 99- | Meli Sylianou (CM) | 99- | Srinivas Katipamula |
| Natascha Castro (CM) | 99- | | | Richard Kelso |
| J. Carlos Haiad (CM) | 96- | | | Jim Kummer |

| | | | | |
|---|---|---|---|---|
| David Kahn (CM) | 96- | | | Clay Nesler |
| Curt Klaassen (CM) | 99- | | | Bob Old |
| Ron Nelson (CM) | 98- | | | Rob Pratt |
| John Seem (CM) | 99- | | | Agami Reddy |
| Jim Winston (CM) | 96- | | | Jeff Rutt |
| | | | | Steve Selkowitz |
| | | | | Pornsak Songkakul |
| | | | | Karl Stum |
| | | | | Jonathan Wright |

**DISTRIBUTION:**

**ALL MEMBERS OF TC/TG/TRG**

**TAC CHAIMAN: Terry Townsend**

**TAC SECTION HEAD: Byron Jones**

**ALL COMMITTEE LIASONS AS SHOWN ON TC/TG/TRG ROSTERS:**

**Program: Emil E. Friberg Manager Of Technical Services: Martin J. Weiland**

**Research:** **Carl F. Speich** **Manager Of Research**: **William W. Seaton**

**Standards**: **Waller S. Clements** **Manager Of Standards**: **Claire B. Ramspeck**

**Journal**: **Kelley Cramm**

**ADDITIONAL DISTRIBUTION: Visitors listed above**

**ASHRAE TC ACTIVITIES SHEET**

**DATE: 1 March 99**

**TC NO. TC4.11 TC TITLE: Smart Building Systems**

**CHAIR: J. Braun VICE CHAIR: J. Mitchell**

**TC Meeting Schedule**

| Location, past 12 mo. | Date | Location, next 12 mo. | Date |
|---|---|---|---|
| Toronto | 6/24/98 | Seattle | 6/22/99 |
| Chicago | 1/26/99 | Dallas | 2/8/00 |

**TC Subcommittees**

| Subcommittee | Chair |
|---|---|
| Fault Detection/Diagnosis | T. Rossi |
| Applications | J. House |

| | |
|---|---|
| Utility/Building Interface | M. Kintner-Meyer |
| Research | G. Kelly |
| Program | C. Lomonaco |
| Standards | R. Hackner |
| Handbook | M. Bailey |

**Research Projects**

1011-RP Utility/EMCS Communication Protocol Requirements

1020-RP Demonstration of Fault Detection and Diagnostic Methods in a Real Building

1043-RP Fault Detection and Diagnostic Requirements and Evaluation Tools for Chillers

1113-TRP Integrated Control for Building Services

**Long Range Research Plan (items 1-5) and Additional Work Statements (items 6-7)**

| **Rank** | **Title** | **W/S Written ?** | **TC Approved ?** | **To RAC ?** |
|---|---|---|---|---|
| 1 | Integrated Control for Building Services[1] | Yes | Yes | Yes |
| 2 | Identification of Degradation Fault Levels in Vapor | Yes (2nd draft) | No | No |

| | | | | |
|---|---|---|---|---|
| | Compression Air Conditioners | | | |
| 3 | Distributed and Hierarchical Fault Detection and Diagnosis of HVAC Systems | Yes (2nd draft) | No | No |
| 4 | Prototyping and Field Testing of ASHRAE's Utility Consumer Interface Models (UCIM) | No | No | No |
| 5 | Development and Evaluation of Fault Detection and Diagnostic Methods for Chillers | No | No | No |
| 6 | Development and Comparison of On-Line Model Training Techniques for Model-Based FDD Methods Applied to Vapor Compression Equipment[2] | Yes | Yes | Yes |
| 7 | Whole Building Fault Detection and Diagnostics | Yes (1st draft) | No | No |

1. Integrated Control for Building Services has been designated TRP-1113. At the Chicago meeting, voting members of TC4.11 selected a contractor for this research project.
2. TC4.11 approved this work statement at the Chicago meeting.

**Handbook Responsibilities - none**

**Standards Activities - none**

**Technical Papers from Sponsored Research - none**

**TC Sponsored Symposia (past 3 years, present, planned)**

| Title | Date<br>(Given or Planned) |
|---|---|
| HVAC System Fault Detection And Diagnosis (Kelly) | Philadelphia, 1/97 |
| Controlling Outdoor Air Ventilation for 62-1989 (Atkinson; TC 1.4 lead with TC4.11 as co-sponsor) | Toronto, 6/98 |
| Fault Detection and Diagnostics - Learning from Building Operations (Ahmed; TC4.6 lead with TC4.11 as co-sponsor) | Chicago, 1/99 |
| FDD Methods and Evaluation Techniques (Castro) | Chicago, 1/99 |

**TC Sponsored Seminars (past 3 years, present, planned)**

| Title | Date<br>(Given or Planned) |
|---|---|
| The Utility/Building Interface: Redefining an Old Relationship (Blanc) | Boston, 6/97 |
| BACnet in the Real World (Bushby; TC 1.4 lead with SSPC 135 BACnet and TG4.SBS as co-sponsors) | Boston, 6/97 |
| Automated Response To Real Time Pricing (Kammerud) | San Francisco, 1/98 |

| | |
|---|---|
| The Delivery of New Energy Services under Electric Industry Deregulation (Nordham; TC4.11 lead with TC 1.4 as co-sponsor) | San Francisco, 1/98 |
| Benefits of Integrating HVAC with Non-HVAC Systems (Newman; TC 1.4 lead with SSPC 135 BACnet and TC4.11 as co-sponsors) | San Francisco, 1/98 |
| Impact of Electromagnetic Interference on Control Systems and Global Standards (Coogan; TC 1.4 lead with TC4.11 and TC 1.9 as co-sponsors) | San Francisco, 1/98 |
| New Platforms and Gateways for Connecting into Building Management Systems (Phelan) | Toronto, 6/98 |
| The Latest Control Communications Technologies (Gartner; TC 1.4 lead with TC4.11 as co-sponsor) | Toronto, 6/98 |
| Customer Experience with Real-Time Pricing Electric Rates (Kintner-Meyer) | Chicago, 1/99 |
| A Peek at a Real BACnet Building… GSA 450 Golden Gate BACnet Pilot Project (Blanc; TC4.11 lead, with TC1.4 co-sponsor) #1 | Seattle, 6/99 |
| What is the Definition of a Smart Building System? What is the Status of Smart Buildings and Where are They? (Lomonaco, TC4.11 lead with TC1.4 as co-sponsor) #3 | Seattle, 1/99 |
| State-of-the-Art Control Devices, Sensors, Motors and Intelligent Actuators (Atkinson; TC1.4 lead with TC1.2, SSPC 135 BACnet, and TC4.11 as co-sponsors) #5 | Seattle, 6/99 |

**TC Sponsored Forums (past 3 years, present, planned)**

| **Title** | **Date**<br><br>**(Given or Planned)** |
|---|---|
| What Are The Priorities For On-Line HVAC Fault Detection And Diagnosis? (Haves) | Philadelphia, 1/97 |
| Exactly What Do Smart Buildings and Control Systems Mean Today? (Newman and Kelly; TC 1.4 lead with TG4.SBS and TCs 1.5 and 4.6 as co-sponsors) | Boston, 6/97 |
| Occupant Driven Interactive Building Control (Bridges; TG4.SBS lead with TC 1.4 as co-sponsor) | San Francisco, 1/98 |
| Now That We Have the BACnet Standard Protocol, are DDC Programming Language and Application Standards Next? (Nesler; TC 1.4 lead with SPC 135 BACnet and TG4.SBS as co-sponsors) | San Francisco, 1/98 |
| CAB and BACnet Similarities and Dissimilarities (Newman; TC 1.4 lead with SPC 135 BACnet and TC4.11 as co-sponsors) | Toronto, 6/98 |
| How Can We Accomplish Multi-Vendor Interoperability in Existing Facilities? (Coogan; TC1.4 lead with SPC 135 BACnet and TC4.11 as co-sponsors) | Chicago, 1/99 |
| What’s ASHRAE’s Role in Deregulation? (Blanc) #2 | Seattle, 6/99 |
| Measuring the Benefit of Fault Detection and Diagnostics (Breuker; TC4.11 lead with TC1.4 as co-sponsor) #4 | Seattle, 6/99 |
| Integration Wars - What/How Will Internet and Other Communications Impact Tomorrow's Buildings? (Coogan or Nesler; TC1.4 lead, with TC4.11 co-sponsor) | Seattle, 6/99 |

| | |
|---|---|
| #6 | |

**TC Sponsored Public Sessions (past 3 years, present, planned)**

| **Title** | **Date**<br><br>**(Given or Planned)** |
|---|---|
| Designing, Installing or Operating Engineers - Who Will Most Impact New Millenium Facilities? (Gartner; TC1.4 lead, with TC9.9 and TC4.11 as co-sponsors) | Chicago, 1/99 |

**Journal Publications (past 3 years, present, planned)**

| **Title** | **When published** |
|---|---|
| None | |

**Minutes summary and activities sheet submitted by: Les Norford, TC4.11 Secretary**

## TC4.11 Minutes

## Chicago: Tuesday, January 26, 1999

### Roll Call, Introductions, Announcements

Chairman Braun called the meeting to order at 3:43 p.m. He distributed the agenda (the call-to-meeting letter and the agenda are in Appendix A). Braun then asked for introductions. A roll call showed that 13 of 17 voting members were present: Braun, Rossi, Mitchell, Kinter-Meyer, Lomonaco, Dexter, Haves, Hackner, House, Blanc, Breuker, Bridges, and Gartner,.

A motion was made (House) and seconded (Braun) to accept the minutes from the June 1998 meeting, with the correction that references to TG in the summary tables be replaced with TC. The motion was approved unanimously.

Braun's announcements included the following: ASHRAE Standard 90 needs members to help review comments; the Continuing Education Committee is looking for new topics and new authors/instructors in order to develop and expand the curriculum of courses offered through ASHRAE; ASHRAE committees are not taking advantage of the Tech Corner in ASHRAE Insights as a means of publicity; program packages for Seattle are due February 12; at Chicago, 80 of 107 sessions were approved; and not meeting program deadlines is a cause for rejection of a proposed session.

**Fault Detection and Diagnosis Subcommittee Report (Rossi)**

Rossi stated that the subcommittee needs a longer time slot at the Seattle meeting.

Seem reviewed progress on **RP-1043 (Fault Detection and Diagnostic Requirements and Evaluation Tools for Chillers)**, for which Purdue University (Braun, PI) is the contractor. The contractor has performed a detailed literature review for fault detection and diagnosis methods and will extend the literature review to cover chiller models. Purdue could not obtain the chiller originally sought, a 50-Ton screw machine, but is now installing a 90-Ton centrifugal chiller. The PMS (at least a subset) plans to meet in a few months with the contractor, before the Seattle meeting. The PMS requests an hour-long review period at the Seattle meeting.

Breuker presented a work statement titled **Development and Comparison of On-Line Model Training Techniques for Model-Based FDD Methods Applied to Vapor Compression Equipment** (Research Priority #6). This work statement is found in Appendix G. It was moved (Rossi) and seconded (Blanc) that the work statement be approved and sent to RAC. The motion passed, 13-0-0 (chair voting). The PES consists of Breuker (chair), Mitchell, Katipamula, Haves and Dexter.

Rossi listed six other research ideas under consideration by the subcommittee:

1. Identification of Degradation Fault Levels in Vapor Compression Air Conditioners (Research Priority #2; Breuker)
2. Development and Evaluation of Fault Detection and Diagnostic Methods for Chillers (Research Priority #5; Dexter, with Katipamula to help in preparation of a work statement)
3. Whole Building Fault Detection and Diagnostics (Research Priority #7; dropped, due to lack of interest in refining the first-draft work statement)

4. Development of Fault Detection and Diagnostics for Sensor Failures (listed as item #10 on the TC's internal research plan (see Toronto minutes); Haberl; Dexter will take over and report in one year)
5. Distributed and Hierarchical Fault Detection and Diagnosis of HVAC Systems (Research Priority #3; Brambley)
6. Quantifying Benefits of FDD and Equipment Monitoring (Rossi, a new idea not on the research plan)

Brambley requested comments on **Distributed and Hierarchical Fault Detection and Diagnosis of HVAC Systems** two months prior to the Seattle meeting. The draft work statement is found in Appendix I.

Breuker reviewed **Identification of Degradation Fault Levels in Vapor Compression Air Conditioners**. This work statement found in Appendix H, describes the first of two phases of work: to obtain the frequency and qualitative level of faults through field surveys and interviews. The second phase, to be described in a later work statement, will focus on quantitative measurement of the severity of faults. There were numerous comments on the work statement, including the need to call to the attention of bidders the need to present in the proposal a plan for obtaining the required information, a question about what equipment types and sizes to be surveyed, concern about how to define a fault in the absence of quantitative measurements, a suggestion to focus on centrifugal machines, for which service technicians may be more skilled, a question about how to deal with repeated calls for the same problem, a question about the existence of data sets on air conditioner faults, and a general concern that this information-gathering effort may not yield substantial useful information. Benzuly and Gillespie will help Breuker revise the work statement.

Minutes of the subcommittee meeting are in Appendix B.

**Applications (House)**

House stated that a TC vote on a contractor for TRP-1113 on **Integrated Control for Building Services** (Research Priority #1) will be conducted in executive session at the end of the meeting (TC voting members and members of the PES only).

House reviewed progress **on RP-1020 (Demonstration of Fault Detection and Diagnostic Methods in a Real Building)**. Commissioning of equipment and FDD methods at the Iowa Energy Center's Energy Resource Station was performed last summer, as was a period of controlled and blind tests. The two contractors, MIT and Loughborough University, submitted reports on the blind tests. Controlled tests were performed in autumn but blind tests were cancelled due to cold weather. Controlled and blind tests in spring will replace the autumn tests. Winter tests are scheduled to start at the end of January. The contractors expect to finish the project on time (July 31, 1999) and will submit a data set as one part of the final report.

The subcommittee has no draft work statements but is considering ideas that range from data links for multiple buildings, self commissioning, and removing barriers to third-party data-analysis software.

Minutes of the subcommittee meeting are in Appendix C.

## Utility/Building Interface (Kintner-Meyer)

Norford reviewed progress on **RP-1011 (Utility/EMCS Communication Protocol Requirements)**. This project requires that the contractor identify existing services and communications protocols, identify possible new services, develop models for the exchange of information for identified services, and make suggestions for ASHRAE's involvement in this area. The PMS is reviewing a substantial draft final report, not yet complete, that was prepared by the contractors, PNNL and Hypertek. The contractors plan to have a complete version to the PMS before the Seattle meeting. The scheduled contract completion date is June 30, 1999.

Kintner-Meyer will take the lead in preparing a work statement for a research project titled **Prototyping and Field Testing of ASHRAE's Utility Consumer Interface Models (UCIM)** (Research Priority #4). This project will extend the work of RP-1011 by prototyping data modules in two phases: implementation of communications for one utility/customer application; and a field test with utilities and 5-10 customers. The key feature of the work is interoperability that goes across existing communications protocols.

Kintner-Meyer noted two other research ideas: encryption for WANs, and an exploration of the kind of information needed by power brokers and other vendors, with attention to rights and confidentiality concerns of customers.

The minutes of the subcommittee meeting are in Appendix D.

## Research Subcommittee (Kelly)

Kelly reviewed the TC's long-range research plan. At this meeting the TC will select a contractor for TRP-1113 (Research Priority #1) and has approved the work statement **Development and Comparison of On-Line Model Training Techniques for Model-Based FDD Methods Applied to Vapor Compression Equipment** (Research Priority #5)**.** One work statement (Research Priority #2, see list on page 2), is likely to be ready for Seattle and three others (Research Priorities #2-4) could be ready at that meeting as well.

**Long Range Research Plan (items 1-6)**

| Rank | Title | TC Action |
|---|---|---|
| 1 | Integrated Control for Building Services (TRP-1113) | Select contractor at Chicago |
| 2 | Identification of Degradation Fault Levels in Vapor | Probable vote at Seattle |

| | | |
|---|---|---|
| | Compression Air Conditioners | |
| 3 | Distributed and Hierarchical Fault Detection and Diagnosis of HVAC Systems | Could be ready at Seattle |
| 4 | Prototyping and Field Testing of ASHRAE's Utility Consumer Interface Models (UCIM) | Could be ready at Seattle |
| 5 | Development and Evaluation of Fault Detection and Diagnostic Methods for Chillers | Could be ready at Seattle |
| 6 | Development and Comparison of On-Line Model Training Techniques for Model-Based FDD Methods Applied to Vapor Compression Equipment[2] | Approved at Chicago |

Work statements on sensor failures and quantitative benefits of FDD could be ready at Dallas.

Kelly stated that RAC is considering a major change in the structure of the Society's Research Plan. Under the proposed change, the long-range research plan would be internal to a TC or TG. The TC/TG would select one topic (as many as three, with section head approval) and prepare a two-page Research Topic Acceptance Request (RTAR). A TC or TG would prepare work statements for those RTARs accepted by RAC. Work statements not previously described in an RTAR would need to be accompanied by a letter of justification from the TC/TG.

Kelly expressed concern that ASHRAE's research will be slowed, despite ample funds, because RAC could review as many as three RTARs from 90 TC/TGs. Also, it is hard for a TC/TG to predict which work statements, from a group under preparation, will be ready first. Kelly suggested that Braun, as TC4.11 chair, contact Dave Tree, incoming RAC chair.

Kelso, an RAC member, stated that the idea of the RTAR system is to prevent TC/TGs from putting significant effort into preparing full-blown work statements that go all the way to Tech Council before being disapproved. Kelso stated that RAC hopes that Tech Council will agree with the RTAR system and not continue to override RAC. Haves, another RAC member, stated that RAC will not be faced with the maximum number of 270 RTARs. Further, TC4.11 would be allowed to submit more than three RTARs, based on its track record. RAC welcomes constructive comments on the proposed change or how to improve the current system.

Braun will share the thoughts of the TC with Tree.

It was moved (Hackner) and seconded (Blanc) that TC4.11 co-sponsor a TC4.6 work statement titled **Building Operation And Dynamics Within An Aggregated Load**. Hackner stated that the work statement previously submitted to RAC was rejected because the project was thought to be EPRI work. TC4.6 has prepared additional justification for the project, which focuses on how to aggregate loads from more than one building and control these loads. Kelly noted that TC4.11 approved the original work statement as a co-sponsor. Benzuly noted that building operators already know how their buildings are working and that utilities already control aggregated loads in the form of cooperative programs. Brandemuehl replied that tools for operating in a cooperative environment are not well developed. Blanc stated that flexible loads are attractive to load aggregators but that most building operators do not know how to increase flexibility. The motion was approved 11-0-1 (chair voting).

## Program Subcommittee (Lomonaco)

Lomonaco reviewed the program for Chicago and presented planned and possible programs for Seattle and future meetings. After discussion about priorities for planned sessions, it was moved (Lomonaco) and seconded (Bridges) that the Seattle program be approved. The motion was passed by voice vote. The program, with priorities identified, is included in the list of TC activities on pages three and four of these minutes, and in the Program Subcommittee Report, Appendix E.

## TC4.11 Web Site

Braun commended Hackner for setting up a web site for TC consideration. The site (http://www.ecw.org/tc411) will be used to post TC minutes, archive old minutes, and post programs. It was moved (Braun) and seconded (House) that TC4.11 establish a web site, as prepared by Hackner. The motion passed by unanimous voice vote.

## Roster

Braun stated that those who would like to join TC4.11 as corresponding members or move from CM status to voting members should speak with him. Changes would take place for the 2000 roster, to go into effect in July 1999.

## New Business

Those present discussed the structure of the TC subcommittees and time slots for subcommittees and PMS meetings. Suggestions included shifting the FDD subcommittee to the last slot on Sunday and providing an extra 30 minutes, and moving the PMS for RP-1043 to another day. Kelly suggested that the TC change the Applications Subcommittee to Systems Integration and Demonstration. Brambley stated that his interests concern applications and that there is more to the subject of smart buildings than fault detection and diagnosis.

**Executive Session**

In executive session for voting members and members of the PES only, the TC voted to recommend to RAC a contractor for TRP-1113.

**Adjourn**

The meeting was adjourned at 6:10 p.m.

**Appendices**

A. Call to Meeting and Agenda
B. FDD Subcommittee Report
C. Applications Subcommittee Report
D. Building/Utility Interface Subcommittee Report
E. Program Subcommittee Report
F. List of Subcommittee Attendees
G. Development and Comparison of On-Line Model Training Techniques for Model-Based FDD Methods Applied to Vapor Compression Equipment
H. Identification of Degradation Fault Levels in Vapor Compression Air Conditioners
I. Distributed and Hierarchical Fault Detection and Diagnosis of HVAC Systems

# Appendix A.

# Call to Meeting and Agenda

**ASHRAE** American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

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1791 Tullie Circle, NE, Atlanta, Georgia 30329-2305 404-636-8400 | Fax 404-321-5478

Reply to: Jim Braun

Ray W. Herrick Labs

Purdue University

W. Lafayette, IN 47907

(jbraun@ecn.purdue.edu)

January 18, 1999

Dear TC 4.11 Member, International Member, or Corresponding Member,

The **TC** on Smart Building Systems and its subcommittees will meet in Chicago according to the following schedule:

TC 4.11 Fault Det. & Diagnostic Sunday (6/24) 3:00-4:00p Sandburg 4 (7)

TC 4.11 Applications Sunday (6/24) 4:00-5:00p Sandburg 4 (7)

TC 4.11 Utility/Bldg Interface Sunday (6/24) 5:00-6:00p Sandburg 4 (7)

**TC 4.11 Smart Building Systems Tuesday (6/26) 3:30-6:00p Parlor B (6)**

Note that some time (e.g., 15 minutes) should be set aside at the end of each subcommittee meeting for program discussions.

The TC is the sponsor or co-sponsor for the following sessions in Chicago:

Seminar 2: Customer Experience with Real-Time-Pricing Electric Rates, Sunday, 8 – 10 am

Symposium CH-99-18: Fault Detection & Diagnostic Methods & Evaluation Techniques, Wednesday, 8-10 am

Public session: Designing, Installing or Operating Engineers -- Who Will Most Impact New Millennium Facilities?, Monday, 3-5 pm

(See the ASHRAE Program Booklet for session locations and to confirm the times.)

Attached is a draft agenda for the full TC 4.11 committee meeting in Chicago. I hope to see you all there.

Jim Braun

Chairman, TC 4.11

### ASHRAE TC 4.11

### Smart Building Systems

### 1999 Winter Annual Meeting, Chicago

## DRAFT AGENDA

**Location: Parlor B (6)**

**Date: Tuesday, January 26, 1999**

**Time: 3:30 - 6:00 p.m.**

1. Roll call and introductions

2. Approval of Minutes from Toronto

3. Announcements

4. FDD Subcommittee Report (Todd Rossi)

1043-RP, Fault Detection and Diagnostic (FDD) Requirements and Evaluation Tools for Chillers (John Seem)

Draft Work Statements

Program plans

Other FDD research activities

5. SBS Applications Subcommittee Report (John House)

1020-RP, Demonstration of Fault Detection and Diagnostic Methods in a Real

Building (John House)

Select Contractor for 1113-TRP, Integrated Control for Building Services (John House)

Draft Work Statements

Program plans

Other activities

6. Utility/Bldg. Interface Subcommittee Report (Michael Kintner-Meyer)

1011-RP, Utility/EMCS Communication Protocol Requirements (Les Norford)

Draft Work Statements

Program plans

7. Research Subcommittee Report (George Kelly)

New Work Statements

Review of 1999 - 2000 Research Plan

8. Program Subcommittee Report (Carol Lomonaco)

Plans for Seattle (6/99)

Plans for Dallas (1/2000)

Plans for future meetings

9. TC 4.11 Website Progress (Rich Hackner)

10. TC 4.11 1999-2000 Roster

11. Additional old business

12. Additional new business

13. Adjournment

# Appendix B.

## TC 4.11 Fault Detection and Diagnostics Subcommittee Meeting

### Minutes

### Toronto, Canada: January 24, 1999

1. Todd Rossi (Chair) began the meeting with an overview of a series of general interest topics relevant to the FDD Subcommittee and its participants. The first topic was a brief review of ongoing research projects (1020-RP and 1043-RP) related to FDD that are being sponsored by TC 4.11. The second topic was a collaborative research effort related to FDD that is being organized by Phil Haves and Steve Blanc. The third topic was an initiative by the NIST Advanced Technology Program on condition-based maintenance.
2. The second item of business was a discussion of a draft work statement entitled "Development and Comparison of Adaptive Model Training Techniques for Model-Based FDD Methods Applied to Vapor Compression Equipment." This work statement was co-authored by Mark Breuker and John House. Todd Rossi provided and brief overview of the work statement and Mark Breuker then gave a more detailed

summary of the objectives and scope of the work. Comments from the subcommittee were positive. There was some discussion of the use of the term "adaptive" and the consensus was to replace "adaptive" with "on-line." There was also discussion about the types of models and training techniques that would be examined. After some debate it was decided that the contractor should be required to examine physical models and neural network models as two of the model types. There was also some discussion regarding the deliverables and it was agreed that computer code should be included as a deliverable of the work. It was agreed that Mark Breuker would make the suggested changes and then bring for a vote before the full TC.

3. The third item of business was a brief update on the status of numerous work statements. Work statement titles/topics, authors, and actions discussed follow:

- Identification of Degradation Fault Levels in Vapor Compression Systems (Author: Mark Breuker; Action: No actions)
- Development and Evaluation of FDD Methods for Chillers (Author: Arthur Dexter; Action: Srinivas Katipamula will assist with work statement)
- Whole Building FDD (Author: Phil Haves; Action: No current activity, so it will be dropped from the list of active research topics)
- Development of FDD for Sensor Failures (Author: Jeff Haberl; Action: Jeff Haberl did not attend the meeting, so Arthur Dexter agreed to work on the work statement for the Dallas meeting)
- Resolving Discrepancies Between Multiple, Hierarchically-Related, FDD Systems (Author: Michael Brambley; Action: Michael Brambley will attempt to distribute a completed work statement prior to Seattle)
- Quantifying the Benefits of HVAC Equipment Monitoring and Fault Detection (Author: Todd Rossi; Action: Todd Rossi has a one-page description of the project and will work to expand it into a full work statement)

4. The fourth item of business was a discussion of program. Program topics are summarized in the minutes of that subcommittee.

Submitted by:

John House

# Appendix C.

# TC4.11 Applications Subcommittee Meeting

### Minutes

### Chicago: June 24, 1999

**Chairman: John House**

**Notes by Todd Rossi**

- There was discussion about merging FDD and Applications subcommittees
- Applications has an on going project RP1020
- There are no active work statements
- John House proposed a new idea: Middleware for integrating building systems together. Information security is a related issue. Deals with information exchange necessary to manage facilities.
- Carol thought there was a recent seminar on this idea that was popular. David Wyon and a BRE researcher are potential speakers to approach. The title was "Big brother is watching you". Occupant driven building operation. It was a forum. People can actually vote on comfort. Security turns on the HVAC equipment. Is there a need to identify the person?
- Michael Brambley discussed his modified work statement on hierarchical FDD methods. Deals with issues like conflict resolution between different vendor's FDD methods. Michael broke it up into two steps: a paper study and a lab or building demonstration. **He will email these two documents to Les to distribute to the TC for review before the next meeting.** He also has an idea about architecture for FDD systems that he offered to write a one-page description.
- Todd Rossi identified an opportunity to reduce barrier to 3rd party data analysis software. Carol asked "Is this a protocol issue"? Carlos suggested that it could plug into another software product like Photoshop. Rob Pratt said that naming conventions is a problem. A JCI rep talked about MetaLink which is a DDE server that makes Metasys data available. Carlos suggested that this data is not identified. John House is encouraging a seminar.
- George Kelly suggested a self-commissioning product that tells when they are not installed correctly. Carol suggested that this could be a seminar. How do we get manufactures to implement this? Is a plug in tester part of this?
- Rob Dodier and Rob Pratt to put together a program or work statement on "Generic Application for FDD Applications". Try for Seattle program?

**Program – Carol**

- Carol will organize program on "Where are the smart buildings?"
- Steve Blanc to work on metering issues program.
- Alternative communication technologies: Pornsak knew of a speaker.
- Barry to expand the "Big brother forum" to a seminar
- Michael Kintner-Meyer will prepare a seminar for Dallas on communication issues.

# Appendix D.

# TC4.11 Building/Utility Interface Subcommittee Meeting

### Minutes

### Chicago: June 24, 1999

**Old Business**

**PROGRAM**

This subcommittee sponsored a seminar at the Winter Meeting titled: *"Customer Experience with Real-Time Pricing"* on Sunday 8:00 to 10:00 am. The seminar was attended by about 100 people. About 30 comments were received with A to B marks.

We reviewed the minutes of this subcommittee meeting held at Summer Meeting 98 in Toronto and discussed the progress of future programs and research topics that were identified at the Toronto Meeting. A summary of this discussion is listed below:

Proposed Seminars:

- "New Metering and service entrance designs". Action: Frank Olken, Marty Burns. No progress on this item.
- "Communications and other issues dealing with integration of fire&safety systems. Action: Michael Kintner-Meyer, deferred to next Winter Meeting
- "Control of multiple buildings or campus complexes". Action: Steve Blanc and Michael Newman. Steve will contact Michael Newman to explore opportunities to find individuals who could report on integrated control strategies for a campus complex.

**RESEARCH**

Michael Kintner-Meyer reported on the state of the ASHRAE Research Project 1113-TRP titled: "Integrated Controls for Building Services", which had been published as a RFP. One proposal was received and reviewed by the PES committee at this Winter Meeting. The committee will make a recommendation for this proposal to the full TC4.11 committee.

We reviewed progress of the research topics proposed during previous Meetings. A summary of this discussion is listed below:

1. Security issues for encryption and authentication when clients interact over WANS through gateways to LAN. Action: Marty Burns. No actions. Marty was not present.
2. What kind of information do vendors want to know about buildings? What's valuable for brokers, vendors, aggregators? What should customer give vendors? Action: Steve Blanc will write a one pager for the next Meeting in Seattle.
3. Les Norford and Michael Kintner-Meyer suggested to write a paper on "Price elasticity of Building Electric Demands" This idea originated during previous Meetings, however, there were no concrete steps mapped out as to how to accomplished this task.
4. "Prototyping and Field Testing of ASHRAE's Utility Customer Interface Models (UCIM)" Action: Chuck McParland, Marty Burns, and Michael Kintner-Meyer. This project is a direct extension of the current ASHRAE research project 1011 RP titled "Utility/Energy Management and Controls System (EMCS) Communication Protocol Requirements". Michael Kintner-Meyer volunteered to lead the writing efforts to produce a work statement for the Summer Meeting in Seattle.

## New Business

1. **Research**

   We discussed the value of "demand bidding" which is one component of the bidding process at a power auction or exchange. At a power exchange, the market clearing price for electricity is determined by the intersection of the supply and the demand curves. We discussed the prerequisite of demand bidding and market advantages associated with it. Michael Kintner-Meyer mentioned that currently, the International Energy Agency is launching a research project investigating the potential market advantages of demand bidding process. No further actions for developing a one-pager were discussed.

2. **Industry News.**

Steve Blanc reported on a change of the power auctions at the California Power Exchange. The Hour-Ahead auction is no longer offered due to too little interest by the California power market. Instead, the Power Exchange offers Day-Of Market auction, which consist of two auctions for on-peak and off-peak power transaction.

# Appendix E.

# TC4.11 Program Subcommittee

## Program for Current and Future Meetings

## Chicago: January 26, 1999

Programs for Chicago, Seattle, Dallas, Minneapolis and were discussed at the general
TC 4.11 meeting. TC 4.11 reviewed numerous candidates for future programs. We voted on the Seattle program and priorities. See below in Section II for the approved list.

Carol Lomonaco will recommend the program for Dallas to TC 4.11 at the Seattle Annual Meeting-June 1999, and request acceptance and prioritization. A list of suggested program for Minneapolis will also be prepared for the Seattle meeting.

I. PROGRAM FOR CURRENT MEETING IN CHICAGO, JANUARY 23-27, 1999 (listed in order as voted on the TC meeting in Toronto June 20 through June 24, 1998.)

1. Sponsoring Committee: TC 4.6 & Co-Sponsoring Committee: TC 4.11

   Fault Detection and Diagnostics – Learning from Building Operations

   Symposium CH-99-05, Osman Ahmed, Sunday 1/24/99 @10:15am, Program SEQ #1196

2. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee:

   Customer Experience with Real-Time-Pricing Electric Rates

   Seminar 02, Michael Kintner-Meyer, Sunday 1/24/99 @8:00am

3. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee:

   Fault Detection and Diagnostics – Learning from Building Operations

   Symposium CH-99-18, Natascha Castro, Wednesday 1/27/99 @8:00am

4. Sponsoring Committee: TC 1.4 & Co-Sponsoring Committee: TC 4.11

   How Do We Achieve Multi-Vendor Interoperability In Existing Facilities?

   Forum 12, Jim Coogan, Sunday 01/24/99 @2:00pm

5. Sponsoring Committee: TC 1.4 and TC 9.9 & Co-Sponsoring Committee: TC 4.11

   Designing, Installing or Operating Engineers---Who will most Impact New Millennium Facilities?

Public Session, Jim Gartner, Monday 01/25/99 @3:00pm, Program SEQ #1195

II. PROGRAM FOR SEATTLE, JUNE 19-23, 1999. (Note: TC 4.11 prioritized, where 1=highest priority). The deadline for the Seattle completed packages is February 12, 1999.

A. FAULT DETECTION AND DIAGNOSTICS

1. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee: TC 1.4

The Value Or The Method Of Measurement And Verification In FDD Applications. What Is Necessary To Evaluate The Benefits?

Forum, Mark Breuker, Track1_____ & Track2_____

Voted as #4 by TC 4.11 in Chicago January 26, 1999 for Seattle Meeting.

B. B. APPLICATIONS

1. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee:

A Peek at A Real BACnet ™ Building…GSA 450 Golden Gate BACnet ™ Pilot Project

Seminar, Steve Blanc, Track1_____ & Track2_____

Voted as #1 by TC 4.11 in Chicago January 26, 1999 for Seattle Meeting.

2. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee: TC 1.4

What is the definition of a Smart Building System? What Is The Status Of Smart Buildings And Where Are They? Asia? Europe? North America?

Seminar, Carol Lomonaco, Track1 CS & Track2 EC, Program SEQ #1197 & 769

Voted as #3 by TC 4.11 in Chicago January 26, 1999 for Seattle Meeting.

3. Sponsoring Committee: TC 1.4 & Co-Sponsoring Committee: TC 4.11 & TC 1.2

State-Of-The-Art Control Devices, Sensors, Motors, And Intelligent Actuators, Etc.

Seminar, Gaylen Atkinson, Track1_____ & Track2_____

Voted as #5 by TC 4.11 in Chicago January 26, 1999 for Seattle Meeting.

1. Sponsoring Committee: TC 1.4 & Co-Sponsoring Committee: TC 4.11

Integration Wars ---- What/How Will Internet And Other Communications Impact Tomorrow’s Buildings.

Forum, James Coogan or Clay Nesler, Track1_____ & Track2_____

Voted as #6 by TC 4.11 in Chicago January 26, 1999 for Seattle Meeting.

C. UTILITY/BUILDING INTERFACE

1. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee:

What’s ASHRAE’s Role In Deregulation?

Forum, Steve Blanc, Track1 SA & Track2 OM, Program SEQ #772,

Voted as #2 by TC 4.11 in Chicago January 26, 1999 for Seattle Meeting.

III. COMMENTS

1. TC 4.11's web site (**www.ecw.org/tc411/program_summary.htm**) should reflect the voted programs and the priority.
2. Future meetings and deadlines are listed below:

| Location | Dates | Package Deadline |
|---|---|---|
| Seattle | June 19-23, 1999 | February 12, 1999 |
| Dallas | February 5-9, 2000 | August 6, 1999 |
| Minneapolis | June 23-27, 2000 | February 1, 2000 |
| Atlanta | February 24-28, 2001 | August xx, 2000 |
| Cincinnati | June 23-27, 2001 | February xx, 2001 |

I. FUTURE PROGRAMS (not prioritized.)

A. TC 4.11 UTILITY/BUILDING INTERFACE

1. DALLAS

   1. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee: TC 1.4

      Case Studies Of Energy Procurement And Aggregation

      Seminar, Les Norford, Steve Blanc & Doug Nordham, Track1_____ & Track2_____

   2. MINNEAPOLIS

   1. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee: TC 1.4

      Deregulation And Energy Efficiency In The State Of California?

Seminar, Les Norford & Carlos Haiad, Track1_____ & Track2_____

3. TBD

1. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee:

Global View of Deregulation…Reporting On Several States.

Seminar, Charles Claar-IFMA & James Yi-JCI, Track1_____ & Track2_____

A. TC 4.11 FAULT DETECTION AND DIAGNOSTICS

1. DALLAS

1. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee:

Fault Detection and Diagnostics (FDD)

Seminar, Jim Braun, Michael Kintner-Meyer, Ian McIntosh, Track1_____ & Track2_____

2. Sponsoring Committee: TC 4.6 & Co-Sponsoring Committee: TC 4.11

Fault Detection….

Symposium, Mike Brambley

2. MINNEAPOLIS

1. Sponsoring Committee: TC 1.4 & TC 1.7, TC 9.9 & Co-Sponsoring Committee: TC 4.11

Practical Experiences In Applying DDC Systems For HVAC Fault Detection And Diagnosis

Symposium, Barry Bridges, Track1_____ & Track2_____

3. TBD

NONE.

A. TC 4.11 APPLICATIONS

1. DALLAS

1. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee: TC 1.4

Communications And Other Issues Dealing With Life Safety, Fire Alarm And HVAC Systems Integration.

Seminar, Michael Kintner-Meyer, Track1_____ & Track2_____

2. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee:

Big Brother Is Watching!!!!!

Seminar, Barry Bridges, Dr. David Wyon, Dr. Cliff, & BRE Person, Track1_____ & Track2_____

1. Sponsoring Committee: TC 1.4 & Co-Sponsoring Committee: TC 4.11

   Should We Consider Expanding The Typical Control Applications From Fan Coil Units To…

   Forum, Clay Nesler

2. Sponsoring Committee: TC 1.4 & Co-Sponsoring Committee: TC 4.11

   Adding New Life To Old Systems. Retrofit Case Studies.

   Symposium, Gaylen Atkinson

3. Sponsoring Committee: TC 1.4 & Co-Sponsoring Committee: TC 4.11

   Control Integration---Practical Solutions.

   Seminar, James Coogan or Clay Nesler

6. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee: TC 1.4

Individual Controls. A Smart Building Approach.

Seminar, Carol Lomonaco, Track1_____ & Track2_____

2. MINNEAPOLIS

1. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee:

A Paper on Research Project RP-1020 AND RP-1043

Symposium, George Kelly

2. Sponsoring Committee: TC 1.4 & Co-Sponsoring Committee: TC 4.11

Central Versas Local Ventilation And Control

Seminar, Rad Ganish

3. Sponsoring Committee: TC 1.4 & Co-Sponsoring Committee: TC 4.11

Should We Continue The Pursuit Of Standard Programming Languages As An Adjunct To BACnet ™ ?

Forum, Clay Nesler, Track1_____ & Track2_____

4. Sponsoring Committee: TC 1.4 & Co-Sponsoring Committee: TC 4.11

Should We Continue The Pursuit Of Standard Programming Languages As An Adjunct To BACnet ™ ?

Forum, Clay Nesler, Track1_____ & Track2_____

3. TBD

1. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee: TC 1.4

Residential Smart Controls.

Seminar, Rosenthal, Track1_____ & Track2_____

2. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee:

Alternate Communications….Powerline Carrier And Others.

Seminar, Barry Bridges, Track1_____ & Track2_____

3. Sponsoring Committee: TC 4.11 & Co-Sponsoring Committee:

A Paper on Research Project RP-1011

Technical Session, Michael Kintner-Meyer, Track1_____ & Track2_____

4. Sponsoring Committee: TC 1.4 & Co-Sponsoring Committee: TC 4.11

Value Of Pre-BACnet™ Control Integration Experience On New Millennium In Building Performance

Seminar, Steve Bushby, Program SEQ #1193

# Appendix F.

# List of Subcommittee Attendees

### Chicago: January 24, 1999

| Name | FDD | Applications | Building/Utility Interface |
|---|---|---|---|
| **Members** | | | |

| | | | |
|---|---|---|---|
| **(through 6/99 meeting)** | | | |
| Jim Braun | x | x | x |
| Todd Rossi | x | x | x |
| John Mitchell | x | x | |
| Michael Kintner-Meyer | x | | |
| Carol Lomonaco | x | x | x |
| Arthur Dexter | x | x | x |
| Philip Haves | | | |
| Rich Hackner | x | x | x |
| John House | x | x | x |
| Steve Blanc | x | x | x |
| Mark Breuker | x | x | x |

| | | | |
|---|---|---|---|
| Barry Bridges | | x | |
| Jim Gartner | | | |
| Jeff Haberl | | | |
| Ron Kammerud | | | |
| Doug Nordham | | | |
| Patrick O'Neill | x | | |
| **Corresponding members** | | | |
| Les Norford | x | x | x |
| George Kelly | x | x | x |
| Mark Bailey | | | |
| Dale Hitchings | | | |
| Natascha Castro | x | x | x |

| | | | |
|---|---|---|---|
| Kirk Drees | | | |
| Tom Engbring | | | |
| Ira Goldschmidt | | | |
| J. Carlos Haiad | | x | x |
| David Kahn | | | |
| Brian Kammers | | | |
| Curt Klaassen | x | x | x |
| Ron Nelson | x | x | |
| Barry Reardon | | | |
| Tim Ruchti | | | |
| Greg Schoenau | | | |
| John Seem | | | |

| | | | |
|---|---|---|---|
| Peter Simmonds | | | |
| Meli Sylianou | | | |
| James Winston | | | |
| **Visitors** | | | |
| Peter Armstrong | x | x | |
| Margaret Bailey | x | | |
| Mike Brambley | x | x | x |
| Mike Brandemuehl | x | | |
| Gaspar Cabrera | x | x | |
| Daniel Choiniere | x | x | |
| Matthew Comstock | x | x | |
| Robert Dodier | x | x | |

| | | | |
|---|---|---|---|
| Cliff Federspiel | x | | |
| Srinivas Katipamula | x | x | x |
| Peter Lehman | | x | x |
| Ian McIntosh | x | | |
| Rob Pratt | x | x | x |
| Agami Reddy | | x | |
| Jeff Rutt | x | x | x |
| Tim Salsbury | x | | |
| Pornsak Songkakul | | x | x |
| Gene Strehlow | | x | |
| Jean-Christophe Visier | x | x | x |
| Tom Watson | | x | |

| | | | |
|---|---|---|---|
| Tom Webster | | | x |
| Jonathan Wright | x | x | |

# Appendix G

# Draft Work Statement

# TC4.11 Smart Building Systems

Revised for Chicago Meeting

# Project Title

Development and Comparison of On-Line Model Training Techniques for Model-Based FDD Methods Applied to Vapor Compression Equipment

**Background**

As the cost of hardware (e.g., sensors, microprocessors) goes down, interest in automated fault detection and diagnostics (FDD) for vapor compression systems grows. For the most part, the methods that have been developed for on-line FDD involve the use of thermodynamic measurements to detect and diagnosis faults that degrade system cooling capacity and efficiency and impact the life of equipment. Methods based upon thermodynamic measurements have been documented by McKellar (1987), Stallard (1989), Yoshimua and Noboru (1989), Kumamaru et al. (1991), Wagner and Shoureshi (1992), Hiroshi et al. (1992), Grimmelius et al. (1995), Stylianou and Nikanpour (1996), and Rossi and Braun (1997). The faults considered include compressor valve leakage, heat exchanger fan failures, evaporator frosting, condenser fouling, evaporator air filter fouling, liquid line restriction, and refrigerant leakage. Typically, temperature and pressure measurements have been investigated because of their relatively low cost.

Most of these FDD methods rely on a mathematical model to predict the fault-free thermodynamic states as a function of the driving conditions that affect the operation of the vapor compression system. For example, on a simple rooftop air conditioning unit, the driving conditions might be the ambient air temperature, indoor air temperature, and indoor air relative humidity. These independent variables uniquely determine the system's dependent variables such as the compressor discharge temperature and suction superheat during fault-free operation. When the thermodynamic states differ from those predicted by the model, residuals are generated. Classification of these residuals is then performed to detect and diagnose faults. An alternative approach would be to compare current model parameters to model parameters generated for normal conditions. The differences in the model parameters could be analyzed by classification techniques to detect and diagnose faults.

The importance of developing an accurate and robust model is crucial to the success of the FDD technique. However, most of research work performed in this field has focused more on classifying the differences between measurements and model predictions (residuals) for both fault detection and diagnostics. Little work has been done in developing and evaluating effective models for fault-free operation. Some of the references mentioned above and along with some additional references including Norford and Little (1993), Haves et al. (1996), Breuker (1997a, 1997b), and Breuker and Braun (1998) have dealt with the issue of developing a model for normal system operation. However, most of the techniques have assumed that a robust experimental data set is available for training the model. If a FDD device is to be added to a vapor compression system that is already installed and operating in the field, there is no simple way to obtain training data at a robust set of driving conditions. In this case a method that learns on-line while the system is operating would be more practical for training a model.

**Justification of Need**

A major contribution to the field of FDD for vapor compression equipment could be made by a study that simply focused on developing a simple, robust, on-line training method of learning a mathematical model for normal system operating states. The development of a mathematical model and the specification of the training technique are viewed as a crucial step in the effort to apply FDD methods to existing vapor compression equipment. The results of this work could be used by a number of researchers in the field to improve their existing FDD methods and push this technology closer to widespread commercialization and application.

**Objectives**

The objective of this work is to develop and compare mathematical models that could be used to predict the fault-free operation of a vapor compression system and the on-line training techniques that allow this model to be trained during day-to-day operation. The findings of this study will be used as the basis for a follow-up study that will focus on demonstrating the most promising model and training technique at one or more field sites.

**Scope**

In order to meet the objectives outlined above, a number of stages of work need to be completed. A suggested order for the project is outlined below. Important information that should be included in proposals for this work statement is included in the section *Other Information for Bidders*.

Task 1: Review published model-based FDD methods

As a first step in the project, the current methods available for FDD on vapor compression equipment should be reviewed. In particular, the reviews should note the measurements used by the FDD techniques and the type of mathematical models that were used to predict normal system behavior. This information will be necessary to determine what measurements on the vapor compression equipment should be modeled for this project. A list of the measurements that will be required shall be submitted to the project monitoring subcommittee (PMS) for approval prior to the commencement of Task 3.

Task 2: Investigate modeling and on-line training techniques

There are a number of fields of study that have attempted to apply on-line training techniques to learn mathematical models for physical systems. The successful contractor will be expected to examine and produce an interim report on the different classes of mathematical models and training techniques that could be utilized to develop a model of a vapor compression system using day-to-day operational data. Examples of different classes of models include physical models, regression models, neural network models, fuzzy models, time-series models, state estimation models, and look-up tables. The interim report should describe the models and training techniques, assess their strengths and weaknesses, and recommend modeling and training techniques from at least four separate classes that will be further developed and customized to the vapor compression problem. Emphasis should be placed on selecting modeling techniques that can be learned without operator supervision. Models that require an expert to tweak parameters are not considered appropriate candidates for study. The report shall be submitted to the PMS for approval prior to the commencement of Task 4.

Task 3: Obtain operating data from a vapor compression system.

In order to begin developing and testing the modeling techniques selected in Task 2, some operating data from a working vapor compression system will be required. To obtain this data, a data acquisition system should be installed on a vapor compression system to record the desired system measurements as the system operates in a normal mode. This task can take place as soon as the measurements and equipment are selected (and approval from the PMS obtained) in Task 1. Care should be taken to ensure that no faults are developing while the data acquisition is in progress.

There are two types of data that may be valuable to obtain: laboratory measurements and field measurements. Beginning the investigation in the laboratory may speed the process of obtaining data at a wide range of driving conditions to investigate the expected form of the models. However, a significant amount of the data (minimum of one month operation during cooling season) should also be obtained from a similar type of system operating in the field, since there may be unmodeled inputs affecting the system that are not present in the laboratory. The laboratory data is only intended to be used to better understand the form of the relationships between driving conditions and the operating states and as a test data set for the trained models. The training of the models must only be done with data that has been obtained from the system(s) operating the field. Enough field data should be collected in this step to ensure a rigorous testing of the modeling and training methods selected in Task 2. The use of existing data is also acceptable provided that the data was adequately documented at the time of collection and provided the data meets the requirements described above.

An experimental plan describing the data collection process shall be submitted to the PMS for approval prior to the commencement of this task (Task 3). If existing data is used, the experimental plan shall be replaced by appropriate documentation to assure the PMS that the data was collected during fault-free operation. Further, the documentation should include appropriate sensor information, driving conditions, sampling intervals, and other information deemed relevant by the PMS.

<u>Task 4: Test the models and training methods</u>

Using the data obtained in Task 3, the models and training techniques chosen for further study in Task 2 shall be compared and evaluated. The data should be divided into testing and training data in order to properly assess the capability of the modeling and training techniques to learn the normal operational behavior of the system. For example, one approach might be to let the methods train using the first week of operating data and then test for the rest the operating data.

Minimum methods of evaluation would be to compare the sum of the squares of the errors and the maximum errors produced the methods. In addition, some methods may be able to give an estimate of the uncertainty of their predictions in different operating regions based on the amount of training data in that operating region. The reliability of this uncertainty prediction should also be assessed. Methods should also be compared based on their abilities to make accurate predictions as a function of the training duration or amount of data used to train the model.

<u>Task 5: Summarize the data and write final report</u>

The contractor shall produce a comprehensive final report detailing all the work undertaken in the project. The report should contain recommendations regarding possible future research topics related to model identification and FDD for vapor compression equipment. All data sets collected and/or used during the course of this project along with all computer code should be thoroughly documented and delivered with the final report. All methods, tools, algorithms, computer code, and data used and developed as a part of this research shall be in the public domain.

**Deliverables**

1. Quarterly progress and financial reports.
2. Oral presentations of the Principal Investigators to the project monitoring subcommittee of TC4.11 at the annual and winter meetings.
3. Modeling and Training Techniques interim report describing mathematical fundamentals and summarizing strengths and weaknesses of the techniques considered.
4. A comprehensive final report that includes the literature review, the Modeling and Training Techniques interim report, detailed description of the demonstration equipment and instrumentation, and conclusions from the study.
5. Electronic copy of data collected during the study and documentation explaining the format of the data.
6. A documented paper copy and electronic copy of all computer code, a users manual guiding future researchers in the compilation and use of this code, and a detailed description of the role of any "canned" software tools (e.g. Numerical Recipes in C, MATLAB Neural Network Toolbox) used in the analysis.
7. A technical paper that summarizes the results of the project.

**Level of Effort**

It is estimated that the project will require approximately 18 months to complete at a cost of about $90,000.

**Other Information for Bidders**

1. Bidders are expected to demonstrate a familiarity with published work related to this study and to provide evidence of previous research that they have performed that is relevant to this study.

1. Bidders responding to this work statement are expected to provide details of the four classes of modeling techniques that they perceive to be most appropriate for this application. Two classes of models that the committee believes should be covered are physically based (gray box) models and neural network models. If the bidder does not choose to include either of these two modeling methods in their proposal, they should explain the reasons that they believe the methods are not suited for this problem. Justification for the selected techniques should also be included in the proposal. Note that multiple models from a given class will be counted as a single modeling technique (i.e., proposing the use of two regression models will require the bidder also propose three other modeling techniques for study). The final selection of modeling techniques to be studied will be decided after the comprehensive comparison of the different classes of modeling and training techniques (Task 2); however, this preliminary selection and justification will weigh heavily on the evaluation of proposals as further evidence of the bidder’s ability to undertake this project.

3. Bidders are expected to submit a preliminary experimental plan outlining the data collection process described in Task 3. The experimental plan should include a description of the equipment and facilities that will be utilized. If existing data is to be used, the bidder is expected to provide in the proposal detailed documentation of the data’s origin sufficient to justify its use in this project. Existing data

must also meet the requirements described in Task 3 (i.e., at least one month of data collected from a field unit during the cooling season).

4. Bidders shall describe how the modeling and training techniques will be compared and what indices will be used to assess the capability of the modeling and training techniques to learn the normal operational behavior of the system.

5. While bidders are only required to obtain data from one system to meet the goals of this work statement, they may specify in their bid to use data from more than one system. Using more than one system to validate the model training technique will help validate the application of the methods to a variety to systems and will be considered as an advantage in the evaluation of the proposals.

**Author**

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John House john.house@nist.gov

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# Appendix H

# Draft Work Statement

# TC4.11 Smart Building Systems

Revised for Chicago Meeting

# Project Title

Identification of Degradation Fault Levels in Vapor Compression Systems.

**Background**

As the cost of hardware (e.g., sensors, micro-processors) goes down, interest in automated fault detection and diagnostics (FDD) for vapor compression systems grows. To date a number of methods have been developed and tested to perform FDD on vapor compression systems. For the most part, the methods that have been developed for on-line FDD involve the use of thermodynamic measurements to detect and diagnosis faults that degrade system cooling capacity and efficiency and impact the life of equipment. Methods based upon thermodynamic measurements have been documented by McKellar (1987), Stallard (1989), Yoshimua and Noboru (1989), Kumamaru et al. (1991), Wagner and Shoureshi (1992), Hiroshi et al. (1992), Grimmelius et al. (1995), Stylianou and Nikanpour (1996), and Rossi and Braun (1997). The faults considered include compressor valve leakage, heat exchanger fan failures, evaporator frosting, condenser fouling, evaporator air filter fouling, liquid line restriction, and refrigerant leakage. Typically, temperature and pressure measurements have been investigated because of their relatively low cost.

While a number of methods for FDD have been developed and documented, there does not seem to be as many publications that document the presence of faults and the corresponding need for FDD in vapor compression systems. It appears that the only publication to address causes of failure for air conditioning equipment was presented by Stouppe and Lau (1989). They summarized the cause of 15,716 failures that led to insurance claims in HVAC&R equipment over an eight-year period from 1980 - 1987. A few studies have addressed the effects of faults on overall air conditioning system performance. Bultman et al. (1993) showed a 7.6% decrease in system COP for a 40% reduction in air flow for an air conditioner. Krafthefer et al. (1987) estimated a 10-13% decrease in COP for typical evaporator filter fouling of a heat pump. Furthermore, they estimated operating cost savings of 10-25% through use of a high efficiency air filter upstream of the evaporator. Rossi and Braun (1996) compared the combined service and energy costs associated with optimal maintenance scheduling for cleaning of condensers and evaporator air filters for rooftop air conditioners. They estimated total cost savings between 5 and 15%. Breuker and Braun (1998) documented the frequency of occurrence and the total cost of some faults on rooftop air conditioners by surveying the database from a HVAC service company. They also quantified the effect of five faults on the capacity and efficiency of a rooftop air conditioning unit.

**Justification of Need**

A number of techniques have been developed for FDD on vapor compression equipment but the demand for the application of this technology has not driven the product to significant levels of commercialization. In order to convince equipment manufacturers and building owners that there is a potential for saving money with the installation of FDD algorithms, the typically occurring levels of these faults and their impacts on performance need to be documented. Another added benefit of this study would be to highlight the need for routine maintenance practices for building operators and the role that artificial intelligence could play in helping to establish the proper scheduling of this maintenance (Rossi and Braun, 1996). The results of this research project could be used to justify the commercialization of automated FDD for vapor compression equipment.

**Objectives**

The objective of this project is to study and document the degradation fault levels that occur in vapor compression systems operating in the field and their corresponding effect on the performance. The first phase of the project (included in this work statement) will determine the frequency and qualitative level of these faults. Since it is unreasonable to cost effectively visit and measure a statistically significant number of vapor compression systems in the field, the source of this data is expected to come from a combination of field surveys and interview/polling of service personnel. In a second phase (not included in this work statement), research will be conducted to determine quantitative levels and the effect of these degradation faults on the performance of the air conditioning system in terms of capacity, efficiency, and possible reliability problems.

**Scope**

In order to meet the objectives outlined above, a number of specific tasks need to be completed in two phases. This work statement outlines the first phase of the project. The work of the second phase will be bid after the completion of the first phase work. A suggested order for the first phase of the project is outlined below:

Task 1: Review previous work

An important first step in this project is the survey of information that is already available on this topic. Publications that estimate the level and frequency of faults that typically occur in vapor compression equipment along with experimental studies on the effect of these faults on system performance should be investigated. Some examples of previous work are reviewed in the Background section of this work statement. Other possible sources of information may include equipment manufacturers, HVAC service companies, electric utilities, or previously published studies by academia or industry. Both industry estimates from qualified sources and specific qualitative and quantitative studies should be included in this work.

Task 2: Identify target equipment and faults

The two most desirable classes of vapor compression equipment to study in this project are unitary air conditioning/heat pump units and chillers. The contractor should specify in their proposal whether they will include either one or both of these systems their work. A number of FDD methods have been developed for different degradation faults in these vapor compression systems. By reviewing the body of FDD research work on vapor compression systems, some of the important faults to study should first be determined. Some previous studies indicate that important degradation faults to consider in these vapor compression systems are refrigerant leakage, condenser fouling, evaporator fouling, liquid line restriction, and reduction in compressor volumetric efficiency. All studies should include these five faults at a minimum. Additional faults to consider may be uncovered during Task 1 and the initial work for Task 2.

Task 3: Formalize method for obtaining data

It is expected that fault data will be obtained by a combination of: 1) surveying the insights of field service personnel in several HVAC maintenance organizations and 2) collaborating with one or more HVAC maintenance companies to visit vapor compression systems in the field and report on the rough quantitative or qualitative level of faults that the systems are experiencing. The targeted faults to study established in Task 2 along with the detailed plan for obtaining the information should be presented to the PMS for approval before proceeding with the rest of the project.

Task 4: Execute plan for obtaining fault data

The contractor will execute the plan approved at the end of Task 3 to obtain the fault data for the study.

Task 5: Summarize the data and write final report

The contractor will write a final report that contains a summary of the findings and any conclusions that can be drawn from the data. The report should comment on the effect of different environmental factors (application, installation procedures, region of country, last date of service) on the levels of faults that were found on the equipment. An appendix should include a well-organized copy of all the hard data from the study. Electronic copies of all the data and all reports (interim and final) should be given to the committee.

The second phase of the work which would start after completion of the first phase would include the following tasks: 1) Developing a plan to obtain quantitative fault data from a number of field installations, 2) Acquisition of field data, 3) Comparison of field data with the data obtained in the first phase of the project, 4) Estimating the effect of the faults (all faults even the once identified in the first phase) on performance the equipment and 5) Summary of results and final report.

**Deliverables**

1. Quarterly progress and financial reports shall be made to the Society through its Manager of Research.
2. Oral presentations of the Principal Investigators to the project monitoring subcommittee of TC4.11 at the annual and winter meetings.
3. A final report that summarizes the literature review, surveys, and conclusions from the study. The final report shall include an executive summary suitable for widespread distribution to the industry and the public. Unless otherwise specified, the final report shall be submitted as six bound copies; one unbound copy, single-sided and suitable for reproduction; and two electronic copies, one in ASCII and one in the word-processing format used to produce the report. The report should also include an appendix with hard data from the field surveys.
4. One or more technical papers shall be prepared in a form suitable for presentation at a Society meeting. The paper(s) shall conform to Section 5 of the Society's "Author's Manual for Technical and Symposium Papers.
5. A Technical Article suitable for publication in the ASHRAE Journal that summarizes the research results.

**Level of Effort for the First Phase**

It is estimated that the project will require approximately 12 months to complete at a cost of about $60,000.

**Other Information for Bidders**

1. The description of the work proposed for Task 3 must include a detailed description of the method to be used in this data collection effort, and the subtasks (e.g., development of survey forms, sample selection, field visits) necessary to implement the approach. A draft list of survey questions provided to these service companies should be provided in the proposal as part of the description of the approach to this task.
2. If the contractor's bid includes one or more HVAC service companies that will be collaborating with the contractor to visit and report on fault levels in vapor compression equipment, a description of this proposed effort must be given in the bid. This should include an estimate of the number systems that will be visited and the methods that will be used to qualitatively evaluate the fault levels that the equipment is experiencing.

**Authors**

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## TC 4.11 Smart Building Systems

Draft Work Statement

January 1999

TITLE

**Resolving Discrepancies Between Multiple, Hierarchically-Related, Fault Detection and Diagnostic (FDD) Systems**

BACKGROUND

Large systems, including buildings, can be represented in a hierarchical structure where the entire system is divided into sub-systems, which are in turn divided into sub-sub-systems, etc., as illustrated in Figure 1.

Figure 1 – Hierarchical representation of a building HVAC system

Fault detection and diagnostic (FDD) methods or software modules can operate on one or more levels or individual entities (i.e., boxes) at different levels throughout this hierarchical structure.

Such systems promise to provide the greatest benefits for large systems (e.g., all the HVAC equipment in a 40 story building) that need the hierarchical structure to divide the system into manageable components, but the hierarchical structure could be applied to smaller buildings and may be of value in implementing diagnostic processes themselves.

When FDD methods operate on hierarchically-related entities, they may produce results that contradict one another. Subsystems have interactions (consider, for example, the chilled water temperature that is produced by the chiller and used by cooling coils). This, along with uncertainty in measured conditions, creates the potential for overlapping and conflicting results when FDD methods are applied to different individual entities at different levels or subsystems in the hierarchy. For example, the chiller FDD might call for a warmer chilled water temperature, while some of the cooling coils it serves call for a lower chilled water temperature. For a building operator to use advice from these distributed, independent FDD systems, some coordination of their results or resolution of conflicts is needed. Conflict resolution might be done manually by the FDD user (e.g., building operator), automatically at a supervisory level (e.g., on the operator workstation), or automatically at distributed points in the FDD system.

This work statement focuses on resolving conflicts between FDD solutions that are likely to utilize distributed computing (i.e., processing takes place at multiple locations distributed throughout the building and/or control system) but it also applies to FDD methods implemented as separate processes or software modules run on the same computer.

## JUSTIFICATION

Fault detection and diagnostic (FDD) techniques are emerging from research and are beginning to be tested in real buildings. Many of these techniques focus on specific HVAC subsystems or components of them; others operate at the whole-building level to identify performance anomalies and identify subsystems causing the anomalies. At the same time, control functions are becoming more distributed with much control processing (computing) taking place at the device or subsystem level, rather than at a central (building-level) location. This provides opportunities for the use of distributed FDD in conjunction with distributed control, yet creates the need to coordinate and resolve conflicts between diagnostic results produced by different FDD systems. This research project responds to that need by providing information that will be needed by the HVAC professions to successfully apply distributed FDD in buildings by developing and evaluating methods for resolving conflicts between FDD systems.

## OBJECTIVE

The objective of this research is to investigate how results from FDD methods applied separately to distributed and hierarchically-related HVAC subsystems and equipment can overlap and potentially conflict with one another. Then, based on this investigation, identify or develop, test and evaluate methods for resolving these conflicts. The final results of this research will be a well-documented evaluation of methods for overcoming conflicts generated by FDD methods or software along with guidance regarding circumstances under which to use each adequately-performing method. The final document shall include detailed examples of method applications.

## SCOPE

The project is divided into five major tasks that the successful contractor is expected to perform:

**Task 1 – Literature Survey**

A literature survey shall be conducted to identify existing methods for supervising and coordinating the interactions of multiple, hierarchically-related FDD or other software modules and associated issues.

**Task 2 – Identify and Select Individual Subsystems, FDD Methods, and Faults**

In this task, the contractor shall select individual building systems, FDD methods that will be applied to them, and the faults that the methods will be capable of detecting and diagnosing. This task shall involve the following steps:

1. Identify at least four building sub-systems and at least two different FDD methods that will be used for examining FDD conflict resolution issues. These systems must be distinct from one another but sufficiently related that faults can occur that impact both systems simultaneously in such a way that FDD methods applied to both of them would produce related and in some cases contradictory results. These subsystems, might be at different levels in the building hierarchy. An example might be an air handler and the filter-coil section of it.

   Illustrate in diagrams how these systems are hierarchically related and how they may potentially interact.

   It is not the intention of this research project to develop new FDD methods. Contractors are encouraged to use existing FDD methods and software, if available.

2. Individual FDD methods will be applied to the selected HVAC subsystems (e.g., air handling units, chillers, and zone controllers) or subsections of them (e.g., filter coil section). Identify how the faults detected and diagnosed by the FDD methods for these systems interact with one another. Also, identify potential conflicts between the results obtained from these FDD methods, and how they would occur.
3. Identify what data (information) the FDD methods will require, what information they will provide, and how FDD results will overlap.
4. Develop four sets of input data each of which will cause at least 2 of the FDD methods to provide conflicting results. Apply the FDD methods to produce at least 4 sets of conflicting results with FDD applied to at least two HVAC subsystems for each data set. For example, one case might be an AHU FDD method complaining that the inlet chilled water is too warm while the FDD method for the chiller's controller calling for an increase in chilled water temperature.
5. The PMS will review and approve the selected HVAC subsystems, the FDD methods selected, and the interactions selected for further investigation.

**Task 3 – Identify and Apply Methods for Conflict Resolution**

1. Identify methods of conflict resolution.
2. Apply the methods to each set of FDD conflicts from Task 2.
3. Develop appropriate metrics for characterizing the success of the conflict-resolution methods and characterize the performance of each for each set of results.
4. Find at least one conflict resolution that satisfactorily resolves each conflict case (set of conflicting results).

**Task 4 – Prepare Guidance for Applying the Successful Conflict Resolution Methods**

**Task 5 – Final Report**

The contractor shall prepare a comprehensive final report that describes all aspects and contributions developed in this project, including:

- the HVAC subsystems selected
- the FDD methods, the faults they identify, and how they are implemented
- detailed descriptions of the conflicts occurring between the FDD methods
- the data sets developed
- descriptions of any software or templates for using software (e.g., spreadsheet templates) used in the investigation
- copies of source code and executable versions for any software code developed as part of the project
- descriptions of all metrics used for evaluating conflict resolution methods
- descriptions and results of all tests and evaluations
- careful documentation of guidance for applying (i.e., using the conflict resolution methods in practice and as part of automated FDD systems.

The report should also identify and document problems and issues that need to be resolved before widespread deployment of independent automated diagnostic software.

**DELIVERABLES**

The contractor shall develop and submit the following items as deliverables for this research project:

a. A literature review that summarizes existing methods for supervising and coordinating the interactions of multiple FDD methods to hierarchically-related systems.

b. A recommendation for the HVAC systems, FDD methods, and conflict resolution methods to be used in the project. This recommendation must be approved by the PMS, prior to further work.
c. Source code for any software programs, tools or templates developed in the project.
d. Monthly teleconferences to address project progress with the PMS. These teleconferences shall be initiated by the Contractor's Principal Investigator and should include all members of the PMS. Minutes of the teleconferences shall be kept by the Contractor and distributed to all members of the PMS at the conclusion of each teleconference.
e. Written Progress and Financial Reports shall be made to ASHRAE through its Manager of Research at quarterly intervals – specifically on or before January 1, April 1, June 1, and October 1 of the contract period.
f. The Principal Investigator shall report in person to ASHRAE Technical Committee (TC) 4.11 at the Annual and Winter ASHRAE meetings and answer questions regarding the project as may arise.
g. A Final Report shall be prepared and submitted to the Manager of Research at the end of the contract period. This Report shall provide complete details of all research carried out on the project. Six (6) copies of the draft Final Report and demonstration product (disk or CD) shall be furnished for review by the Project Monitoring Subcommittee.
h. Following approval by the Project Monitoring Subcommittee and TC 1.5, final copies of the Final Report and demonstration product shall be

furnished as follows:

- Six (6) copies of an Executive Summary of the project suitable for wide distribution to the industry and the public;
- Six (6) bound copies of the Final Report;
- One unbound copy of the Final Report, printed on one side only, suitable for reproduction;
- Four (4) 3.5" diskettes with copies of the Final Report -- two (2) with the Report in ASCII format and two (2) with the Report in the most current version of Microsoft Word or Corel WordPerfect;
- Six (6) copies of the final demonstration product on CD or 3.5" diskettes;
- A "master" copy of the CD or diskette for the demonstration product suitable for reproduction.

b. One or more Technical Papers shall be submitted in a form suitable for presentation at a Society meeting. The papers shall conform to ASHRAE’s "Submitting Manuscripts for ASHRAE Transactions" which may be obtained from the Special Publication s Section. (On the ASHRAE Home Page, these guidelines are titled "Meeting Paper Preparation" and can be found under "How to Participate."
c. All papers or articles submitted for inclusion in ASHRAE publications that result from this research project shall be submitted through the Manager of Research — not directly to the publication’s editor.
d. A Technical Article suitable for publication in the *ASHRAE Journal* may be requested by the TC or *Journal* Editor. Such an article would be considered a voluntary contribution to the profession and is not a project deliverable.

LEVEL OF EFFORT

The project is expected to require approximately 12 months to complete at a cost of about $75,000.

OTHER INFORMATION FOR BIDDERS

1. Bidders are expected to demonstrate a familiarity with published work related to this study and provide evidence of previous research that they have performed in the area of FDD for HVAC systems.

REFERENCES

AUTHORS

Michael Brambley

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